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Wear Performance Evaluation of a Contemporary Dual Mobility Hip Bearing Using Multiple Hip Simulator Testing Conditions

LaQuawn Loving, Reginald KinFay Lee MS, Lizeth Herrera, Aaron Paul Essner MS, Jim Edward Nevelos PhD

Stryker Orthopaedics, 325 Corporate Dr. Mahwah, New Jersey

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ABSTRACT

The dual mobility hip bearing concept combines a small bearing with a large diameter bearing through a dual articulation system, potentially increasing the stability of the hip. Bearings with two articulations introduce concerns of whether or not wear might be increased compared to a conventional bearing. We therefore evaluated the wear performance of a dual mobility hip bearing using sequentially cross-linked and annealed polyethylene under the conditions of impingement, abrasion, and when the mobile liner becomes immobilized at either the inner or outer diameter. We found the wear performance of this dual mobility hip is dictated by the conditions experienced by the smaller inner articulation and by the polyethylene material. The highest wearing group wore 75% less than a single articulating conventional gamma/inert polyethylene bearing.

The number of primary total hip arthroplasties (THAs) has continued to increase each year and the expectation is that the number will continue to increase [1,2]. Furthermore, contemporary patients receiving THA are more active than the historical candidate for hip arthroplasty surgery while life expectancy continues to increase [3].

The dual mobility concept was developed by Bousquet in the 1970's [4]. The dual mobility hip is comprised of two unconstrained articulations between three different components; a femoral head, polyethylene insert, and an acetabular shell (Fig. 1). The design provides the benefits of a metal on metal articulation with its effective large bearing [4–6]. Highly crosslinked polyethylene bearings have increased in usage and their early results have been reported [7–10]. Their preliminary wear rates are low and have the potential to reduce the incidence of osteolysis potentially leading to longer implant life [7,8,11]. Combining the technology of the dual mobility hip system with a highly crosslinked polyethylene may make the dual mobility hip an excellent large bearing articulation [4,9,12].

In the process of developing any advanced bearing system for total hip arthroplasty, aggressive screening/testing should be utilized to help more accurately predict the success of the bearing in vivo. Hip joint wear simulation is currently one of the tools used to help evaluate the wear performance of different bearing materials and designs [13–15] by recreating different conditions that may occur in-vivo with total hip arthroplasties [16].

Clinical evaluation of previous dual mobility designs has reported intra-prosthetic dislocation of the implant due to the loss of retaining power of the polyethylene insert and/or fibrosis causing any one articulation to cease movement [4,6,17]. Also, the dual mobility hip has a freely moving insert that can achieve continued movement after femoral neck/acetabular insert impingement [4–6]. In addition, the second articulation introduces an additional area that may be susceptible to abrasion. Different abrasion mechanisms are common occurrences in THA, and can cause accelerated wear of the polyethylene component [18]. This study will describe the testing results of a dual mobility hip under these non-ideal conditions: abrasive, induced impingement conditions, as well as immobilization of the insert at either of the two articulations using a hip joint simulator. These tests will assist in gaining further understanding of the wear performance of this mobile hip bearing.

Materials and Methods

Dual mobility components were the Restoration ADM Mobile Bearing Hip system (Stryker, Mahwah, NJ). The femoral heads were 28 mm Cobalt Chrome alloy (CoCr). The acetabular shells were 48 mm polished CoCr alloy on the inner diameter and plasma spray coated with Commercially Pure titanium and hydroxylapatite on the 54 mm outer diameter. Polyethylene components had a 28 mm inner diameter (ID) and 48 mm outside diameter (OD) made from compression molded GUR 1020 which had been sequentially

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Reprint requests: LaQuawn Loving, Stryker Orthopaedics, 325 Corporate Drive, Mahwah, NJ 07430.

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Fig. 1. Dual mobility hip bearing.

irradiated and annealed three times at a dosage of 30 kGy each time for a total dose of 90 kGy, (X3 Stryker, Mahwah, NJ). These components represent the median size offering for this construct.

Machine and Kinematics

All testing was conducted on MTS hip joint wear simulators (MTS, Eden Prairie, MN). Each simulator station consists of a 23° inclined block which rotates at 1 Hz to provide composite flexion/extension, abduction/adduction, and rotational motion. Stationary acetabular components are mounted superiorly to femoral components and along the same vertical axis. A specimen chamber surrounds this assembly and allows for submersion in 50% alpha calf serum (≈20 g/L protein) (Alpha Calf Fraction, Hyclone, Logan UT). Compressive loading is applied axially with a maximum of 2450 N following the physiological profile determined by Paul [19]. All fixtures are composed of non-corrosive materials and all fixtures and components were ultrasonically cleaned prior to testing.

Immobilized Testing

Fibrosis around the acetabular shell has been identified as a potential cause of immobilization of the outer bearing [4], although it is not clear if this tissue growth would develop and seize outer motion or result from no or limited motion being present. Regardless, this condition was recreated by restricting movement between the acetabular shell and polyethylene insert to assess performance impact. This effectively reduced the bearing to a fixed 28 mm bearing. To achieve immobilization of the outer bearing, the acetabular insert was seated directly into a modified fixture that then allowed clamping across the face of the insert. Clearance was provided between the neck and the clamping fixture to allow only the inner bearing to articulate (Fig. 2). In addition, the scenario of the bearing being reduced to a single articulation with a fixed 48 mm polyethylene outer head was also simulated, i.e. if the junction between the 28 mm femoral head and acetabular insert were to become immobilized, although this clinical situation is difficult to theorize. To simulate the immobilization of the inner bearing, the polyethylene insert was modified into a full polyethylene femoral head with a taper that incorporated an anti-rotational mechanism (Fig. 2). Mobile bearing hip components under standard conditions were used as control samples. Articulation was conducted at a 50° inclination angle with the femoral neck angled at 40°.

Impingement Wear Testing

The mobile nature of the insert in the dual mobility hip allows femoral-neck/acetabular-insert impingement with minimal resistance by allowing the insert to displace upon contact [6]. This design is intended in this particular construct. However, this construct may also be susceptible to femoral-neck/acetabular-insert impingement when the outer bearing is fixed. We tested the system under two different impingement conditions; induced impingement of the acetabular insert against the femoral neck when the insert is unconstrained (mobile impingement) and acetabular-insert/femoral-neck impingement when the insert is immobilized or somehow held in place (fixed impingement).

To create the impingement conditions when the acetabular insert is unconstrained, the femoral neck was positioned at 17° and the acetabular component was placed at 45° of inclination. At these angles, impingement occurs at either the superior or inferior surfaces on the femoral neck during the initial gait cycle. After the first cycle, the design of the mobile bearing components will allow the articulation to run impingement free for majority of the testing cycle based on design geometry with impingement occurring randomly and the insert re-aligning itself repeatedly throughout the duration of testing.

In order to create impingement conditions when the acetabular component is fixed, the acetabular component was fixed in the same manner as the immobilized outer bearing test. Impingement was applied using a controllable torque system. The system is controlled using a spring mechanism to induce variable levels of torque based on the desired impingement conditions. Impingement conditions were based on the 28 mm inner diameter of the acetabular cup, a body weight of 183 lb, and an inclination angle of 50°. Insert/head anteversion was controlled to create a bending moment proportional to joint force resulting in a torque of approximately 25% of body weight upon impingement. This model has been described elsewhere [20]. Mobile bearing hip components tested under standard conditions at 50° of inclination were used as controls.

Abrasion Testing

Abrasion may occur at either or both articulations. Femoral heads were scratched using a Rockwell C diamond indenter to create a multi-directional sinusoidal abrasion pattern as previously described [21]. Acetabular shells were scratched using a modified version of the pattern used for the femoral heads due to the shell's concave geometry (Fig. 3). Both components were scratched at their pole. Samples were tested under three different conditions; femoral head scratched, acetabular shell scratched, and both femoral head and acetabular shell scratched. Testing was conducted using 0° inclination angles for the acetabular component with the femoral necks at 90° from the horizontal to help achieve this goal. Dual mobility components under standard conditions at the same neck and inclination angles were used as controls.